Phreatic Karst Conduit Flood Pulse Modeling

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Introduction

Karst conduits supply about 25% of the world's population with water [2], including nearly 90% of Florida's drinking water [3]. Input of conduit water to the matrix changes the water in the matrix out of chemical equilibrium forming a variety of geochemical interactions, including precipitation [4, 5]. Interaction between conduit and matrix water also has implications for karst solute budget, residence time the tributary, and contaminant transport [5]. A conduit flood is one mechanism that pushes conduit water into the matrix. Conceptually we borrow from Cooper and Bisognin [6] normal mix of conduit storage-throat flood water to model a flood water passing through a phreatic conduit. This event is modeled in the matrix using a two-dimensional time-dependent model of Darcy's law.

Background on Conceptual Basis

Figure 2. Cooper and Bisognin [6] model of two-dimensional flow system, ζ - 1-dimensional model geometry.

Over forty years ago [7-9], Cooper and Bisognin [6] developed a single but important one-dimensional, linear model of streambank storage of a passing flood water in a surface stream or channel. Given the flood water details, the model explained water level changes in the permeable aquifer bounding the channel. It is clear that the conduit is a high point of conduit water to the matrix for a duration slightly shorter than the flood pulse. As the flood recedes, the flow in the conduit begins to drop, and the hydraulic head near the conduit reduces. The conduit brings a low point of matrix water over a time period much longer than the flood pulse duration.

COMSOL Modeling

In this poster we present only numerical model results, achieved using the finite element method through the commercial code COMSOL Multiphysics. One advantage of using a computer model, rather than an analytical solution is the ease with which we can modify our parameters to include simple or complex conduits. COMSOL was configured to allow for the inclusion of a second (secondary) conduit, where mixing or leakage across the top boundary by making the top boundary a prescribed flux boundary.

Figure 3. COMSOL model 3-domain and finite-element mesh.

The normal condition of the matrix is assumed to be in local equilibrium with the conduit (where local gradient is in the unsaturated vadose zone). A flood event, measured as an increase in head in the conduit, passes through the conduit. The result is a high point of conduit water to the matrix for a duration slightly shorter than the flood pulse. As the flood recedes, the flow in the conduit begins to drop, and the hydraulic head near the conduit reduces. The conduit brings a low point of matrix water over a time period much longer than the flood pulse duration.

Volume of Flood Water Stored

Flood water is stored in the matrix for much longer than the flood duration. The volume of flood water stored in the matrix follows the general decay of the peak pulse as it draws slowly. Depending on aquifer properties, it can take three orders of magnitude longer than the flood pulse duration for the aquifer to fully drain the flood water volume.

Figure 4. Dimensionless flux of water into and out of a conduit.

Figure 5. Volume of flood water in matrix due to conduits flood event. Flood pulse is very slow due to drain from matrix after the flood event. Important parameters, (1-100%) of total flood volume remains in the capillary to a time scale of magnitude longer than the flood pulse duration.

Flux of Flood Water

The natural condition of the matrix is assumed to be in local equilibrium with the conduit (where local gradient is in the unsaturated vadose zone). A flood event, measured as an increase in head in the conduit, passes through the conduit. The result is a high point of conduit water to the matrix for a duration slightly shorter than the flood pulse. As the flood recedes, the flow in the conduit begins to drop, and the hydraulic head near the conduit reduces. The conduit brings a low point of matrix water over a time period much longer than the flood pulse duration.

Figure 6. Discharge of water to matrix after flood event. When the area under the curve above the matrix is 0.5 or less, a conduit-event can be considered normal. A flood event occurring within the matrix, Figure 7. The flux of water to the matrix during and after flood event. Depending on aquifer properties, 15-45% of flood water volume remains in the matrix at a time one order of magnitude longer than the flood pulse duration.

Mass of Flood Water Stored

Suppose the conduit flood pulse has a different chemistry than the matrix water. How might the matrix respond to the chemically different floods water? We saw that the volumetric storage of the flood wave involves a pressure rise, or head pulse moving into the matrix, whereas storage of chemically tagged flood water involves a pressure pulse of magnitude longer than the flood pulse duration for the aquifer to fully drain from the flood water volume.

Figure 7. Discharge of water from matrix during and after flood event. A conduit-event can be considered normal. A flood event occurring within the matrix, Figure 8. The flux of water to the matrix during and after flood event. Depending on aquifer properties, 15-45% of flood water volume remains in the matrix at a time one order of magnitude longer than the flood pulse duration.

Future Work

Objective & Questions

Objective. Model conduit-matrix exchange caused by conduit floods. A flood is a temporary increase of conduit pressure head.

Question 1. What are the dependencies of volume sequestered in the conduit and matrix during flood events?

Question 2. What amount of flood water is stored in the matrix?

Question 3. What are the implications for contaminant sequestration?

Conclusions

1. Water is transferred to the matrix during the flood faster than it is transmitted back to the conduit after the flood.

2. 20-60% (depending on aquifer properties) of the flood water remains in the matrix at a time one order of magnitude longer than the flood pulse duration. It can take over three orders of magnitude longer for the flood pulse duration for the aquifer to fully drain from the flood water volume.

3. Some of the water draining to the conduit due to the flood is predicted matrix water. This leads to a sequestration of flood water in the matrix.

References


Figure 8. Multiple floods with water particle displacements. A new conduit flood water sequestered in the previous flood discharge into the matrix.